Beyond seafloor spreading: Neogene deformation and volcanism in the Adare Basin

R. Granot,[1] S. C. Cande,[2] J. M. Stock,[3] R. W. Clayton,[4] and F. J. Davey[5]

[1]Scripps Institution of Oceanography, Mail Code 0220, La Jolla, CA 92093-0220, USA, <rgranot@ucsd.edu>
[2]Scripps Institution of Oceanography, Mail Code 0220, La Jolla, CA 92093-0220, USA, <scande@ucsd.edu>
[3]California Institute of Technology, Mail Stop 252-21, Pasadena, CA 91125, USA, <jstock@gps.caltech.edu>
[4]California Institute of Technology, Mail Stop 252-21, Pasadena, CA 91125, USA, <clay@gps.caltech.edu >
[5]Institute of Geological and Nuclear Sciences, Lower Hutt, New Zealand, <F.davey@gns.cri.nz>

Summary Seafloor spreading at the Adare spreading axis, lasting from the Middle Eocene until the Late Oligocene (43 – 26 Ma), constrains the motion between East and West Antarctica throughout that period of time. Subsequent faulting in the Adare and Northern Basins from Late Oligocene until present-day (26 - 0 Ma) is poorly resolved and might provide a key constraint on the motion between the two plates. Here we present preliminary results of new seismic reflection and seafloor mapping data acquired on geophysical cruise 07-01 aboard the R/VIB Nathaniel Palmer. Our results suggest that the style of deformation has changed from spreading-related faulting into a diffuse normal faulting (tilted blocks) that trend NE-SW with little resultant E-W extension. Recent volcanic activity is distributed throughout but tends to align with the NE-SW trend. Formation of the Terror Rift within the same time frame suggests that the pole of rotation might have drifted northward.

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Introduction

Late Mesozoic extension between East and West Antarctica initiated the West Antarctic rifting (WAR) boundary with the formation of basins and ridges within the Ross embayment (Cooper et al., 1987; Fitzgerald, 1992, Figure 1). Further Cenozoic extensional motion between the two plates marked by the uplifted Transantarctic Mountains was mainly localized in the western side of the Ross Sea (Northern and Victoria Land Basins, Cooper et al., 1994). Seismic investigation (e.g., Cooper et al.,1987; Fielding et al., 2006) as well as drilling projects (e.g., Cape Roberts Science Team, 2000) indicate that recent extensional activity along the WAR was localized within western Victoria Land Basin at the Terror Rift since 17 Ma.

Linear marine magnetic anomalies off the northwestern part of the Ross Sea have elucidated the fossil ultraslow Adare spreading center (12.5 mm/yr full spreading rate, Figure 1b). Spreading accounted for 170 km of ENE-WSW extension between chrons 18 and 9, i.e., from 43 to 26 Ma (Cande et al., 2000). The continuity of these magnetic anomalies constrains the amount of extension that might have taken place since the cessation of spreading in the Adare Basin. Neogene extension, if any, must have been oriented parallel to the magnetic anomalies. Muller et al. (2005) have shown that the abnormally large offset on the Adare Trough-bounding faults is the result of reactivation during the 5 m.y. after spreading stopped.

Continuous magnetic anomalies, Bouguer gravity anomalies, and undisrupted sedimentary sequences that cross the shelf and continue into the Northern Basin suggest that the opening of the Adare Basin was accompanied by the opening of the Northern Basin where massive and focused magmatic intrusions were likely to have been emplaced (Cande and Stock, 2006). One of the primary unknowns with respect to the evolution of the rift is how extension within the northern part of the WAR (i.e., Northern and Adare Basins) was accommodated after the cessation of seafloor spreading. Resolving the post-spreading structures within the Adare Basin may shed light on the evolution of the Antarctic rift for the last 26 m.y.

Here we present preliminary results from a geophysical cruise conducted aboard the R/VIB Nathaniel Palmer (cruise 07-01). We collected a grid of more than 2,700 km of multichannel seismic reflection data together with a detailed multibeam bathymetric map of the seafloor within the basin and across the shelf (Figure 1). This dataset enables us to map the Late Oligocene to present stratigraphic sequences.

Seismic Reflection data

Seismic reflection data were acquired with a 1200 m oil-filled streamer. For most of the lines, the seismic energy source was an array of six generator-injector air guns with a capacity of 225 cubic inches each. Seismic profiles across the shelf were acquired with an array of six Bolt air guns with a total capacity of 2125 cubic inches. Data were recorded on 47 channels (out of 48). The data were 8 second records with 0.002 s sample rate and a spacing of approximately 28 meters. Initial processing of the data included velocity semblance analysis every 100 common mid-points. Subsequent processing included stacking and F-K migration.

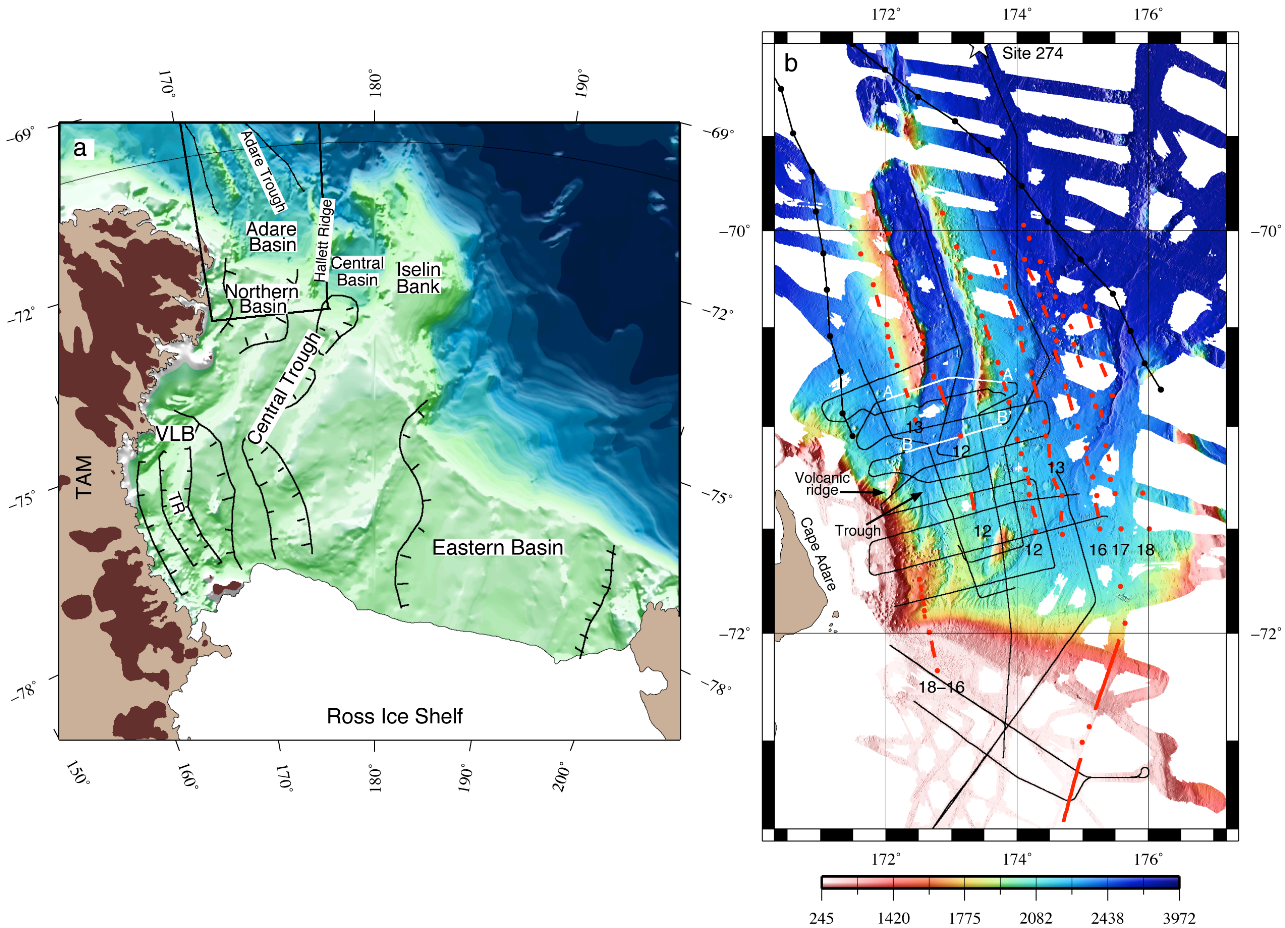

Figure 1. Tectonic setting of the West Antarctic rift system. a. Main structural features of the Ross embayment. TR, VLB, and TAM stand for the Terror Rift, Victoria Land Basin, and the Transantarctic Mountains, respectively. Black rectangle delineates the location of Figure 1b. b. Multi-beam bathymetry map of the Adare and Northern Basins. Red dashed-dotted lines delineate the magnetic anomalies formed at the Adare spreading center and Northern Basin. Black lines show the recently acquired multichannel seismic reflection lines and white lines represent the profiles shown in Figure 2. Star shows the location of DSDP site 274. Note the NE-SW trend of the volcanic ridge and morphology originating east of Cape Adare. These features are Neogene in age.

Preliminary results

High quality seismic reflection data allow us to trace the oceanic basement and sediment contact throughout the basin. In most lines in the Adare Basin, due to the relatively deep water, water bottom multiples were not a problem. Interpretation of the seismic stratigraphy was initially based on the published seismic stratigraphy (Muller et al., 2005) and was tied into the sedimentary sequences of DSDP site 274 (Figure 1b). The sedimentary sequences thicken southward and westward toward the continental shelf and show large depositional variability between the different parts of the basin. Discrepancies between the correlation of the lowermost unit within and east of the Adare Trough have led us to adjust the interpretation of the sequence inside the trough.

Brittle Deformation in the Adare Basin

Seafloor spreading-related normal faulting show basement offsets of up to 500 meters (calculated with seismic velocity of 1600 m/s, Hayes et al., 1975, Figure 2). These faults are predominantly dipping toward the spreading axis and trend perpendicular to the flow-line. The Adare Trough bounding faults are traced southward across the Adare Basin, buried under a thick sedimentary sequence, following the trend of the trough.

Intriguing block faulted structures are imaged south and southwest of the Adare Trough (for example see Figure 2). These features trend NNW-SSE but they are spatially located in an en-echelon pattern with an overall trend of NE-SW that points toward the Cape Adare and Hallett volcanic provinces in the south. Individually, these faults are steep causing little tilt on the strata indicating that there was vertical motion without much horizontal extension. Fault-tilted blocks are the cause of the disappearance of the Adare Trough to the south and are probably responsible for the NE-SW trend of the morphological trough originating at Cape Adare which merges into the Adare Trough at the north (Figure 1b). The timing of activity on these blocks is constrained by the tilted sequence and the syn- and post-faulting sedimentary deposits suggesting activation during the early Late Oligocene - Early Miocene (?). Many of these faults re-activate spreading related faults and hence are dominated by their NNW-SSE trends (Figure 2). Active faults are frequently observed (presented by J.S. elsewhere). The total amount of extension on these post seafloor-spreading faults is minimal based on the seismic profiles and on the continuity of the magnetic anomalies.

Volcanism in the Adare Basin

Two primary phases of volcanic activity were active in the entire time span recorded in the Adare Basin. Early volcanic activity is characterized by an onlapped overlying sedimentary sequence suggesting seafloor spreading related volcanism. Submarine lava flows are shown in places by a pseudo layering of structures imaged within the top 0.2 seconds of the basement. The second phase of volcanism overlies the entire sediment sequence indicating very recent (Pliocene to present-day) volcanism. For the most part these features form individual volcanic knolls, although some have coalesced to build a volcanic ridge oriented NE-SW. This ridge borders the tilted blocks and defines the western edge of the overprinted rift. Volcanism seems to originate from the western side of the Northern Basin (Figures 1b and 2). Commonly, young volcanism is associated with faulting, either recently active or fossil faults.

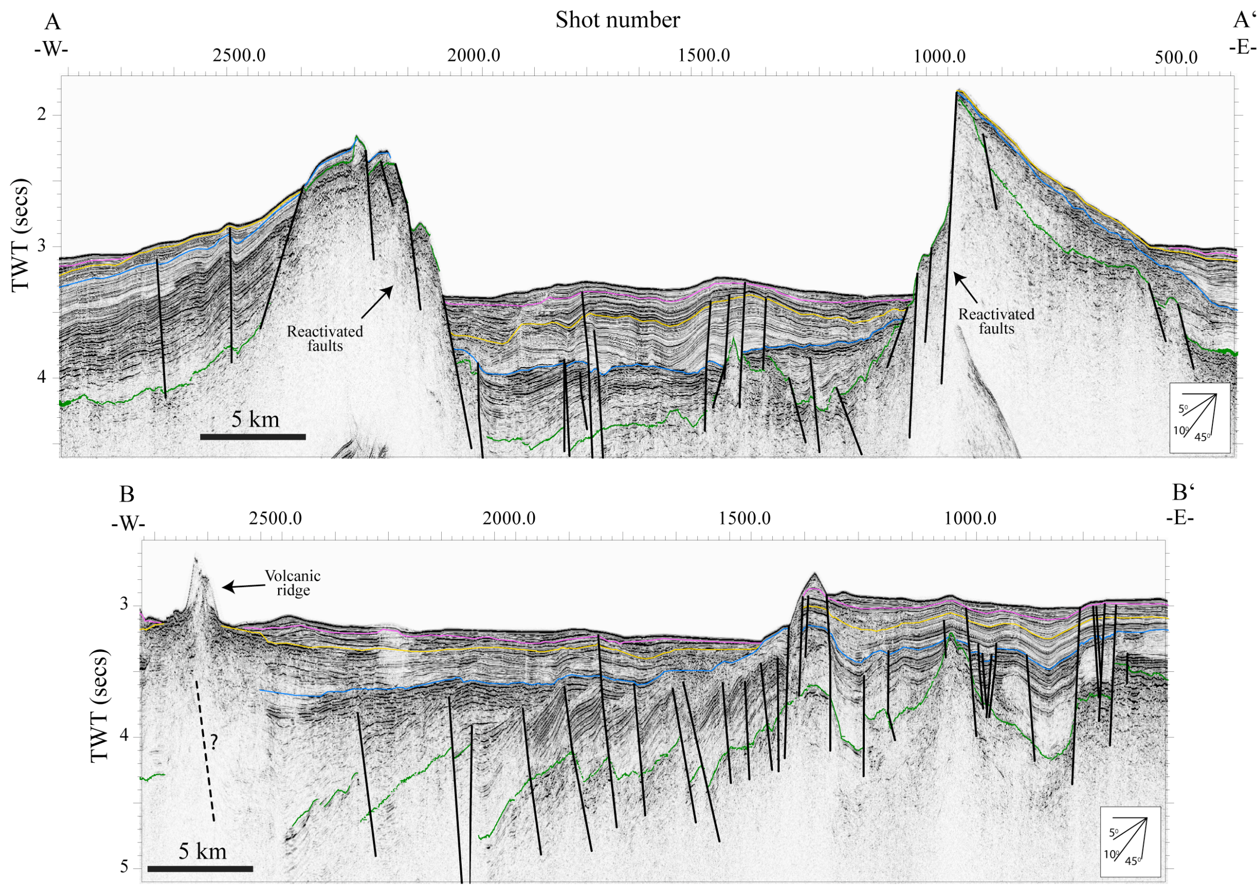

Figure 2. Representative seismic profiles. Profile A-A' crosses the southern end of the Adare Trough. Tilted Late Oligocene (?) unit (top unit is defined by blue line) suggests reactivation of the faults that bound the trough. The Blue line traces the most pronounced unconformity in the center and west side of the basin. Profile B-B' shows tilted blocks with the recent to active volcanic ridge on its western side. Yellow and red lines trace the base of the Mid-Miocene and Pliocene units, respectively. Top of oceanic basement is shown by the green line. Note vertical exaggeration of 1:7.5.

Discussion

The evolution of rifting in the Adare and Northern Basin throughout the Neogene is poorly known. Our findings reveal that shortly after spreading ceased along the Adare spreading center, an oblique, wide NE-SW rift connecting the

Adare Trough to the western side of the Northern Basin became active. Reactivation of the Adare Trough-bounding faults and the formation of the oblique rift might have coincided in time implying that this oblique rift was active mostly during the late Oligocene (within 5 m.y. after cessation of spreading). Throughout the Neogene deformation has been confined to vertical motions with minor horizontal extension.

The formation of the Terror Rift within the western side of the VLB indicates that the central part of the WAR was active during the Neogene (Cooper et al., 1987; Fitzgerald, 1992). Assuming that the locus of deformation of the northern part of the WAR is located within the Adare Basin, we suggest that the Neogene rotation pole for West and East Antarctica was located somewhere north of the Adare Basin, implying that it migrated northward from a southerly position (Davey et al., 2006) during the Oligocene-Early Miocene. Geodetic (Donnellan and Luyendyk, 2004) and seismic measurements (Behrendt et al., 1991) show that there is currently no significant motion between the two plates, suggesting that the motion of the pole might have been the precursor to the unification of East and West Antarctica into a coherent plate.

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